iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: IX Month of publication: September 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue IX, September 2017- Available at www.ijraset.com

Design and Optimization of Multi-Leaf Spring by Finite Element and Grey Relation Method

Jayesh Raj Pal[1], Arun Singh Kushwah[2]
[1]*Research scholar, ME Department, ITM University, Gwalior, India*
[2]*Assistant Professor, ME Department, Gwalior, India*

Abstract: ***The Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials has high strength to weight ratio, good corrosion resistance. The objective is to compare the different types of composite material and load carrying capacity, stress stiffness and weight savings of composite leaf spring with that of steel leaf spring. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle TATA ACE EDGE are selected for this work investigation. Similar dimensions of conventional leaf spring are used to design in Solid works of composite multi leaf spring material for analysis that is E- Glass/Epoxy, Carbon Epoxy and Graphite Epoxy unidirectional laminate. Finite Element Analysis with full load on 3-D model of composite multi leaf spring is done using ANSYS 14.5 and the analytical results are compared with experimental results. Run the 16 experiment with the combination of load and material which gives output responses in terms of stress, deflection and weight. Compare the all material with their respective load and select the best one by comparison. Optimize the responses of 16 combinations by Grey Relation Analysis for the better input parameter against output responses.***
Keywords: Leaf Spring, Solid Works, ANSYS, Grey Analysis.

I. INTRODUCTION

Leaf springs are mainly used in suspension systems used to absorb the shock loads in automobiles such as L.C.V, H.C.V. It used to carry lateral loads, brake torque and driving torque with shock absorbing [1]. Leaf spring covers advantages over helical spring are that the ends of the leaf spring can be guided along a definite path because it deflects to act as a structural member along with energy absorbing device. According to previous studies made, a material which had maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring [2]. The leaf springs get more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile. Performance measures of any leaf springs are its stiffness and fatigue life. [1].

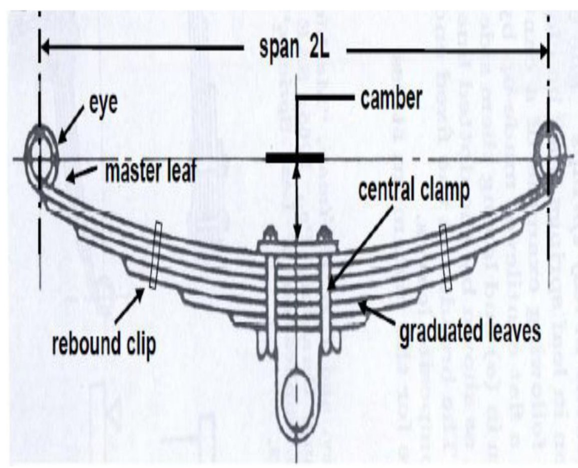

Fig.1 Leaf spring assembled at rear axle of automotive & Multi-Leaf Spring [2]

A. Principle of Leaf Spring

With the introduction of composites, a better suspension system along with better ride quality can be achieved. In designing of springs, strain energy becomes the major factor [1]. The relationship of the specific strain energy can be expressed as;

$U = \sigma^2/\rho E$

Where σ is the strength, ρ is the density and E is the Young's Modulus of the spring material.

B. Composite Materials

When two or more materials are combined then it results in better properties than those of the individual components which can be used alone, can be defined as Composite material. Every material retains its separate chemical, physical, and mechanical properties, when compared to metallic alloys. Composite materials offers advantages such as high strength and stiffness, combined with low density, when compared with bulk materials, which allows for weight reduction for the finished part [3].

C. Applications

Composites material has their commercial and industrial applications on major structural application areas which includes aircraft, space, automotive, sporting goods, and marine engineering.

Other applications include such as structural chassis components, such as drive shafts and road wheels, have been successfully tested in the laboratories and are currently being developed for future cars and vans.

1) Benefits

a) Weight reduction & High strength: Composites are light in weight, compared to most woods and metals & far stronger than aluminum or steel.

b) Corrosiveness & Low Thermal Conductivity: Composites resist damage from the weather and from harsh chemicals & are low conductor of heat and cold and are good insulator.

c) Design Flexibility & Durable: As compare to other materials composites can be molded into complicated shapes more easily & have a long life and need little maintenance.

II. PROBLEM FORMULATION

Based on the problems and past research gap analysis objective of work are focused on compare the load carrying capacity, stresses, deflection and weight savings of composite leaf spring with that of steel leaf spring. And paying attention on composite materials by replacing steel in conventional leaf springs of a suspension system to reduce stresses, deflection are follow some objective;

A. Select the vehicle leaf spring for calculate its dimension and its effective load.

B. Deign the leaf spring in CAD software with assemble which provide the requisite dimension to the body structure as well as to bear the load in actual condition.

C. Design the input parameters for analysis in ANSYS tool. As per the design with selected parameters perform the analysis and record the responses.

D. Optimize the responses with suitable multi-objective technique.

E. Compare these responses with respect to load for selected the material of leaf spring.

III. MATERIALS DESCRIPTION

A. Steel and composite material

PROPERTY NAME	VALUE AND UNIT
Young's Modulus	200000 Mpa
Tensile Strength	650~880 Mpa
Elongation	8~25%
Fatigue	275 Mpa
Yield strength	350~550 Mpa
Density	7700 Kg/m3
Resistivity	0.55 ohm×mm^2/m
Poisson's ratio	0.27-0.30
Elastic modulus	190~210 Gpa

Table 1 EN47 material properties [1]

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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Volume 5 Issue IX, September 2017- Available at www.ijraset.com

S.NO	PROPERTIES	EGLASS/ EPOXY	CARBON EPOXY	GRAPHITE EPOXY
1	Tensile stress at X direction E_x (Mpa)	43000	177000	294000
2	Tensile stress at Y direction E_y (Mpa)	6500	10600	6400
3	Tensile stress at Z direction E_y (Mpa)	6500	10600	6400
4	Poisson ratio at XY direction P_{xy}	0.27	0.27	0.023
5	Poisson ratio at YZ direction P_{yz}	0.06	0.02	0.01
6	Poisson ratio at ZX direction P_{zx}	0.06	0.02	0.01
7	Shear Modulus at XY direction G_{xy} (Mpa)	4500	7600	4900
8	Shear Modulus at YZ direction G_{yz} (Mpa)	2500	2500	3000
9	Shear Modulus at ZX direction G_{zx} (Mpa)	2500	2500	3000
10	Density δ (kg/mm^3)	0.000002	0.0000016	0.0000015

Table 2 Orthotropic properties of Composite materials [10]

B. *Selection of lcv and dimension*

NAME OF DATA	DATA	UNIT
Total num. of leaves	5	_ _
Span length	940(+ -3)	Mm
Material name	EN47	_ _
Total length(Eye to Eye)	956	Mm
Free camber at no load condition	100(+ -4)	Mm
Thickness 1ST ,2ND and 3RD	7	Mm
Thickness 4TH and 5TH	6	Mm
Width of leaf	60	Mm
Outer Diameter of Eye End	45.8 ~ 46	Mm
Inner Diameter of Eye End	58	Mm

Table 3 SELECTED LCV – TATA ACE EDGE 102.

Basic requirements of load: Maximum capacity = 2250 Kg = 2250 x 10 = 22500 N TATA ACE EDGE 102 is equipped with 4 nos. of semi-elliptical leaf spring,
So load acting on the leaf spring assembly = 22500÷4 = 5625 N
Calculation of load and effective length of leaf spring:
Consider the leaf spring is cantilever beam, $2 \times W = 5625$, $W = 5625 \div 2$, $W = 2812.5$ N.
Now On basis of parameters calculation leaf spring are designed in SOLID WORKS and FEA in ANSYS v14.5. FEA of every material are run and results are shown in below fig.

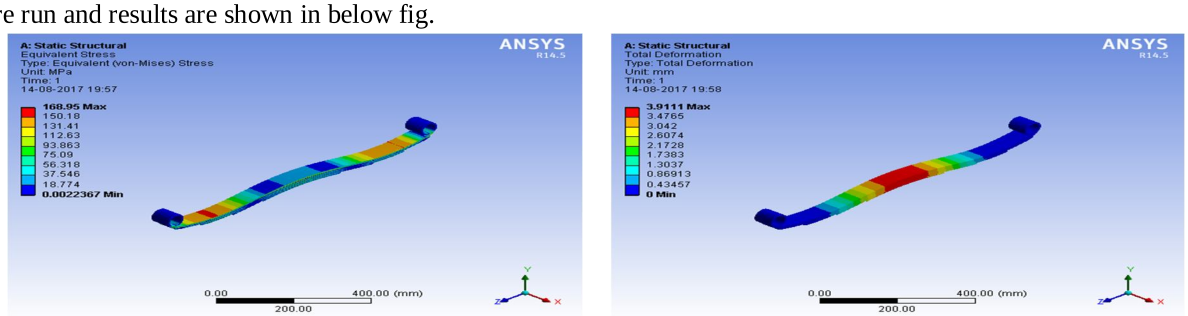

Fig 2 EN47 stress and deflection at 5625 N

On similar way, stress and displacement of every material was calculated and response table is formed below.

IV. OPTIMZATION

Based on analysis in ANSYS software with respect to design parameter their responses are tabulated in table 4, these responses are in terms of maximum stress and maximum deflection.

S. No.	L (N)	M	W (Kg)	σ (MPa)	δ (mm)
	Input Parameter			Output Response	
1	5625	EN47	11.665	168.95	3.911
2	5625	E glass	3.03	58.038	13.008
3	5625	Carbon Epoxy	2.424	58.145	8.381
4	5625	Graphite Epoxy	2.4088	57.611	13.039
5	5600	EN47	11.665	168.2	3.894
6	5600	E glass	3.03	57.78	12.95
7	5600	Carbon Epoxy	2.424	57.887	8.344
8	5600	Graphite Epoxy	2.4088	57.355	12.981
9	5575	EN47	11.665	167.45	3.876
10	5575	E glass	3.03	57.522	12.892
11	5575	Carbon Epoxy	2.424	57.628	8.307
12	5575	Graphite Epoxy	2.4088	57.099	12.923
13	5550	EN47	11.665	166.7	3.859
14	5550	E glass	3.03	57.264	12.835
15	5550	Carbon Epoxy	2.424	57.37	8.269
16	5550	Graphite Epoxy	2.4088	56.843	12.865

Table 4 Response Table [4]

Applying Grey Relational Analysis (GRA) is an impacting capacity method.

$$X_i(k) = \frac{max(y)_i - (y)_i}{\max(y)_i - \min(y)_i} \qquad \ldots\ldots(1)$$

Normalizing Equation

Grey Relation Coefficient $G_i(k)$ for the k^{th} response characteristics in the i^{th} experiment can be expressed as

$$G_i = \frac{L_{min} + \varepsilon L_{max}}{L_i(k) + \varepsilon L_{max}} \qquad \ldots\ldots\ldots(2)$$

Where $L_i(k)$ is the k^{th} value in L_i different data series. L_{max} and L_{min} are the global maximum and global minimum values in the different data series, the mean of the range of $\varepsilon = 0.5$,

After GRC, Grey Relation Grade (Γ) is calculated, the highest value of GRG is the optimum result. GRG is calculated as:

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} G_i \qquad \ldots\ldots \quad (3)$$

The magnitude of γ reflects the overall degree of standardized deviation.

Normalizing and Calculating Grey Relation Coefficient and Grey Relation Grade [4] in below table:

S. No.	L	M	W	X_i σ	X_i δ	G_i σ	G_i δ	Γ
1	5625	EN47	11.665	0	0.994336	0.333333	0.988798	0.661066
2	5625	E glass	3.03	0.989341	0.003377	0.979126	0.334085	0.656606
3	5625	Carbon Epoxy	2.424	0.988386	0.507407	0.977299	0.503731	0.740515
4	5625	Graphite Epoxy	2.4088	0.993149	0	0.986484	0.333333	0.659909
5	5600	EN47	11.665	0.00669	0.996187	0.334827	0.992432	0.66363
6	5600	E glass	3.03	0.991642	0.009695	0.983559	0.335502	0.65953
7	5600	Carbon Epoxy	2.424	0.990687	0.511438	0.981715	0.505785	0.74375
8	5600	Graphite Epoxy	2.4088	0.995433	0.006318	0.990949	0.334743	0.662846
9	5575	EN47	11.665	0.01338	0.998148	0.336333	0.99631	0.666322

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
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10	5575	E glass	3.03	0.993943	0.016013	0.988032	0.33693	0.662481
11	5575	Carbon Epoxy	2.424	0.992998	0.515468	0.986189	0.507856	0.747022
12	5575	Graphite Epoxy	2.4088	0.997716	0.012636	0.995454	0.336165	0.665809
13	5550	EN47	11.665	0.02007	1	0.337854	1	0.668927
14	5550	E glass	3.03	0.996245	0.022222	0.992545	0.338346	0.665446
15	5550	Carbon Epoxy	2.424	0.995299	0.519608	0.990686	0.51	0.750343
16	5550	Graphite Epoxy	2.4088	1	0.018954	1	0.337599	0.6688

Table 5 Calculation of GRC and GRG [4]

V. RESULT AND DISCUSSION OBTAINED

From optimization done above we get result for optimum load, stress, deflection and optimum material to be suggested for replacement of conventional steel.

Optimum stress and deflection for Carbon epoxy at load 5550N is shown in Fig.3

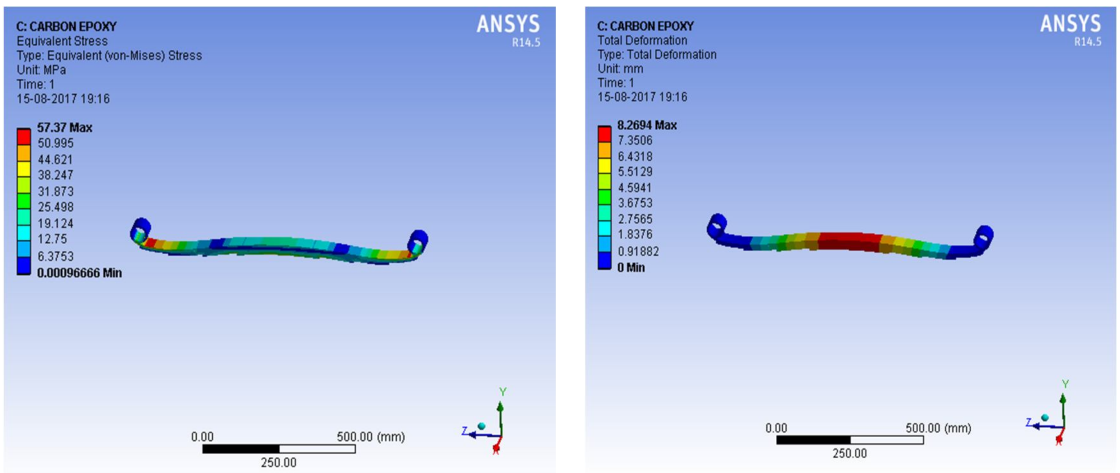

Fig 3 CARBON EPOXY stress and deflection at 5550 N

A. *Comparison of GRG*

	5625	5600	5575	5550	Average GRG	Rank
EN47	0.661066	0.66363	0.666322	0.668927	0.66498625	2
E glass	0.656606	0.65953	0.662481	0.665446	0.66101575	4
Carbon Epoxy	0.740515	0.74375	0.747022	0.750343	0.7454075	1
Graphite Epoxy	0.659909	0.662846	0.665809	0.6688	0.664341	3

Table 6 GRG Comparison

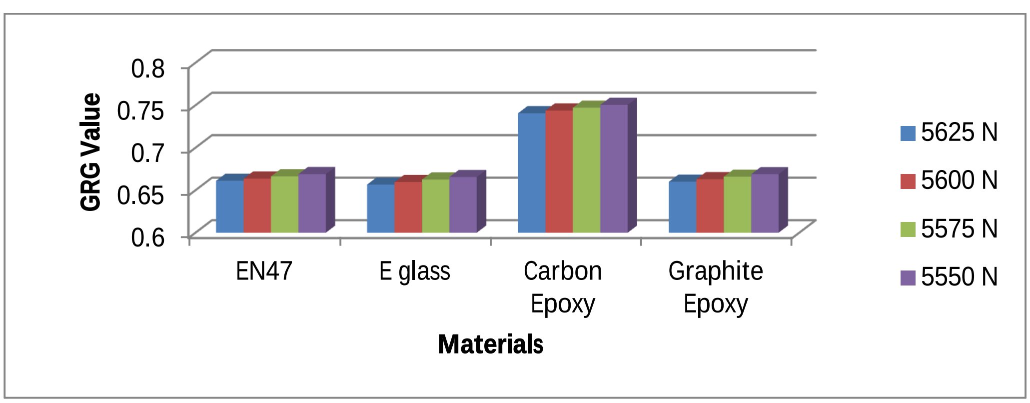

Fig. 4 Comparison Graph of GRG

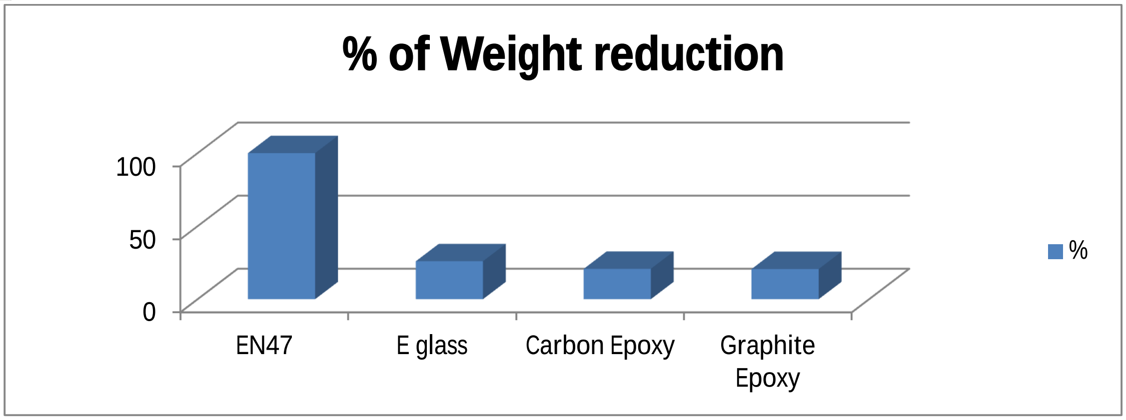

Fig 5 Percent of weight of each material [1]

VI. CONCLUSION

From the static analysis results it is found that there is a maximum displacement of 13.039 mm in the Graphite epoxy spring and the corresponding displacements in Steel E-glass / epoxy, and carbon/epoxy are 3.911mm, 13.008 mm and 8.3811mm respectively on maximum load. From the static analysis results it is found that there is a maximum stress of 168.95 MPa in the steel spring and the corresponding displacements in E-glass/epoxy, Graphite epoxy and carbon/epoxy are 58.038 MPa, 57.611 MPa and 58.145 MPa respectively on maximum load. From the optimization by grey relation analysis observed the minimum stress and deflection simultaneously drawn on load 5550 N with Carbon Epoxy material. By comparing GRG with respect to load and material the optimize material is Carbon epoxy with all load, its minimum stress are found 57.37 MPa and deflection 8.2694 mm. Among the three composite leaf springs, only Carbon/epoxy composite leaf spring has optimum stresses and deflection than the other material leaf spring. Carbon/epoxy composite leaf spring can be suggested for replacing the steel leaf spring from stress and stiffness point of view. As comparing the weight of steel to other material carbon epoxy has optimum weight is 2.424 as comparing with steel percent the reduction in weight for suggested material is 79.219. But the minimum weight percent reduction is obtained 79.35 % of Graphite epoxy which is almost equivalent to carbon epoxy.

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